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The Study of Exciting Process of Seismogenic Emissions at Epicenter by Magnetic Flux Based on the Statistical Analysis

Takeo YOSHINO and Hikaru SATO

Sugadaira Space Radio Observatory, University of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo 182, Japan

1. Introduction

The study of electromagnetic emissions related to earthquakes began in 1980 as a cooperative project between Japan and the U.S.S.R. The first emissions were observed at 16:33 JST (UT + 9 hours) on March 31, 1980, at the Sugadaira Space Radio Observatory, University of Electro-Communications (Sugadaira, Nagano, Japan). The observation frequency was 81 kHz and the magnitude of the earthquake was about 7. The depth of its focus was about 380 km and the epicenter (in Kyoto prefecture) was about 250 km from Sugadaira Observatory. Beginning 50 minutes before the main shock, there was an anomalously high change in the background noise level, a change more than 15 dB. At the same time, the VLF wide-band whistler recorder at Sugadaira Observatory registered unusual impulsive emissions at frequencies below 1. 5 kHz before the earthquake (Gokhberg *et al.*, 1982).

Since 1980, we and our colleagues have observed several emission events at 81–82 kHz just before earthquakes. The events were observed by using our multipoint observation network, with direction-finding capabilities, the Tokyo area (Yoshino *et al.*, 1985).

A recent statistical analysis for 26 earthquakes occurring between 1985 and 1990 and observed by our Seismogenic EM Emission (SEE) monitering network in the Kanto area yielded two interesting and important results. The first is a statistical correlation between the magnitude of an earthquake and the distance of its epicenter from the observation points. A line through the minimum detectable intensity shows a beautiful correlation as shown in Fig. 1 (data from Yoshino *et al.*, 1993). The equation for this line is,

$$M = 2.2 + 1.4 \log E,$$

where M is magnitude and E is the distance (km) to the epicenter. The second is that there is no correlation between the magnitude and the depth of the focus point of an earthquake as shown in Fig. 2 (data from Yoshino, 1993). These results suggest a scenario for the generation mechanism of SEE. The electromagnetic wave seems to

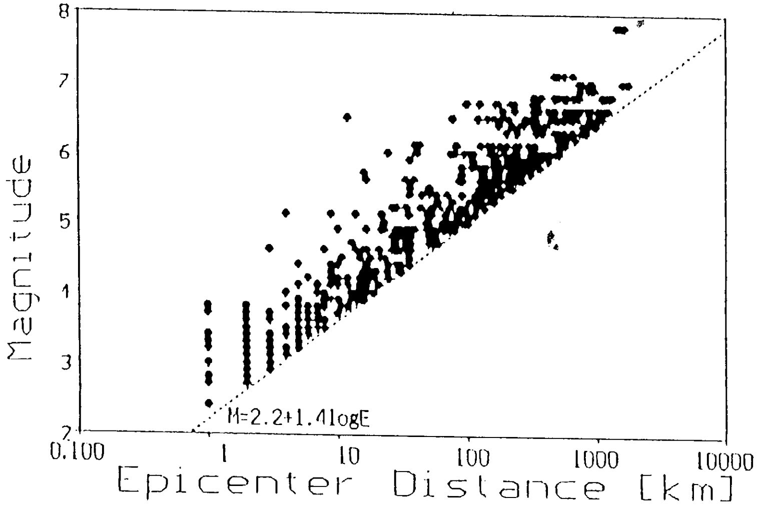

Fig. 1. Magnitude of earthquakes vs. distance between epicenter and observation point.

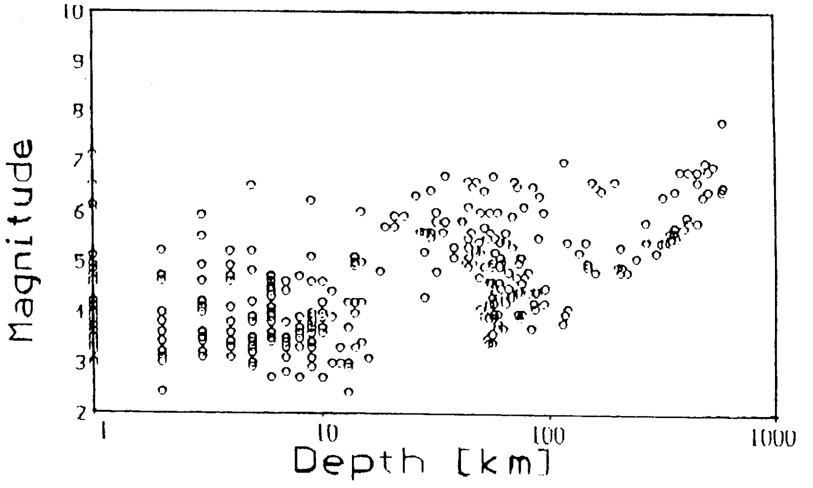

Fig. 2 Magnitude of earthquakes vs. depth of focus when we received the SEE signal at observation point.

be regenerated at (or above the ground surface) of the epicenter and the energy of electromagnetic wave mode cannot propagate and penetrate through the soil and rocks. We obtained a private communication from NOSC of the U.S. Navy in 1991, telling us that when a submarine transmitted an emergency signal by means of ELF and VLF radio transmitter from the ocean bottom, the most effective detection system for the rescue forces are magnetic sensors on patrol planes flying at low altitudes or on patrol boats. These sensors can be used to determine the position of submarged submarine, but the electric field has never been detected or used for this purpose.

The probability of SEE detection around the Kanto area is listed in the following table for earthquakes with epicenters within 300 km from the observation point.

Table 1.

Magnitude	Probability
7.5–7.0	100
7.0–6.5	45
6.5–6.0	23
6.0–5.5	16
5.5–5.0	6.6
5.0–4.5	No data
4.5–4.0	5.2

This paper describes our new explanation, based on my statistical data, of the mechanism by which SEE is radiated in the epicenter area.

2. New Theory of See Radiation Mechanism

If the electromagnetic impulsive energy is generated by the crushing of rock before an earthquake (Cress *et al.*, 1987; Mizutani and Yamada, 1987), the energy should be carried in soil, rock, and sea water without much attenuation by electromagnetic mode wave. But measurements of the electric and magnetic field intensities near artificial seismic explosion tests, clearly showed that the intensity of the magnetic field differed from that of the electric field. In the artificial seismic explosion experiment at Toyama prefecture in 1991, the observation result showed that the magnetic field intensity was always 10 to 25 dB greater than the electric field intensity at the same point.

These results led us to believe that the energy of SEE generated at rock crush is mainly carried to the earth's surface by the magnetic flux. To explain this scenario, we propose a new idea. When the impulsive and DC-like magnetic field induces a closed loop of magnetic flux as shown in Fig. 3, the displacement current is induced perpendicular to the loop. A simple Maxwell equation gives this displacement current:

$$\nabla X\dot{H} = j\omega\varepsilon\dot{E}.$$

The displacement current is that a term in this equation will be regenerated by the

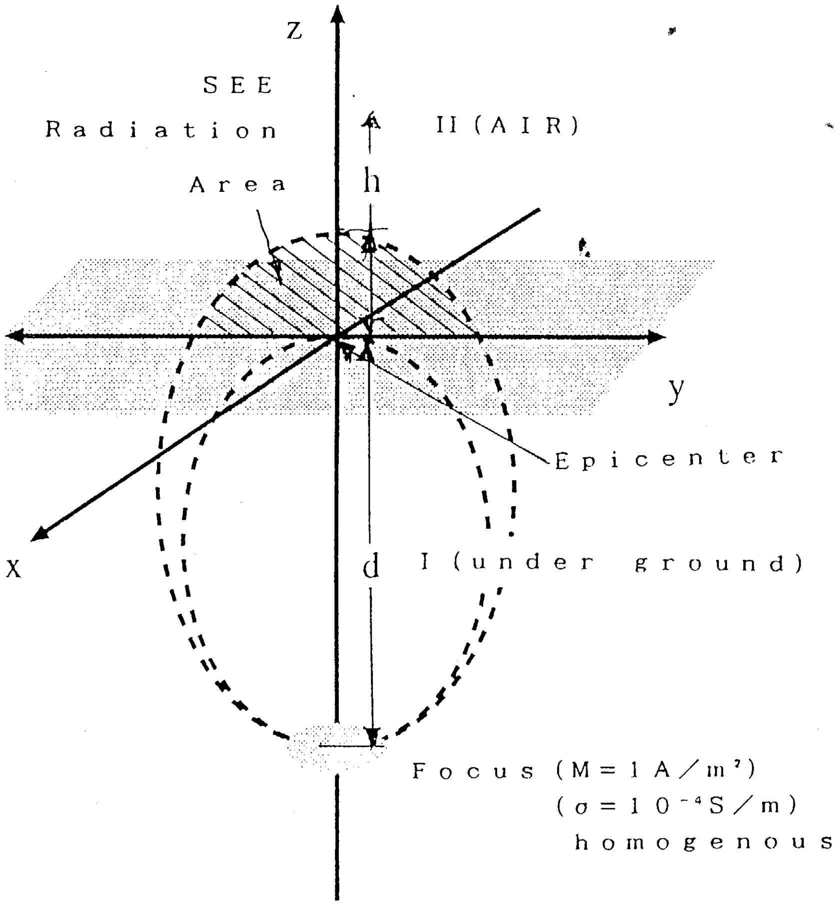

Fig. 3 The geometry of the magnetic flux loop.

new electromagnetic wave excited by DC-like impulsive magnetic field on and top of the earth's surface around the epicenter. And this regenerated electromagnetic wave will be radiated from the portion of loop lifted over the ground surface and propagated to observation point.

Here we try to investigate the calculation of energy loss during transmission from the focus point to the surface. We do this by using a hypothesis that applies the formulas of Banos (1966) and of Fraser-Smith and Budenik (1980). The calculated attenuation is reasonable, and the results are shown in Fig. 4.

We calculated this attenuation under the assumption that the soil and rock has a homogenaus structure, the value of exciting current is 1 A/m, and the electric conductivity in VLF band is 10^{-3} S/m at the focus point. Figure 4(a) shows the relationship between the converted field aligned electric current densities on the

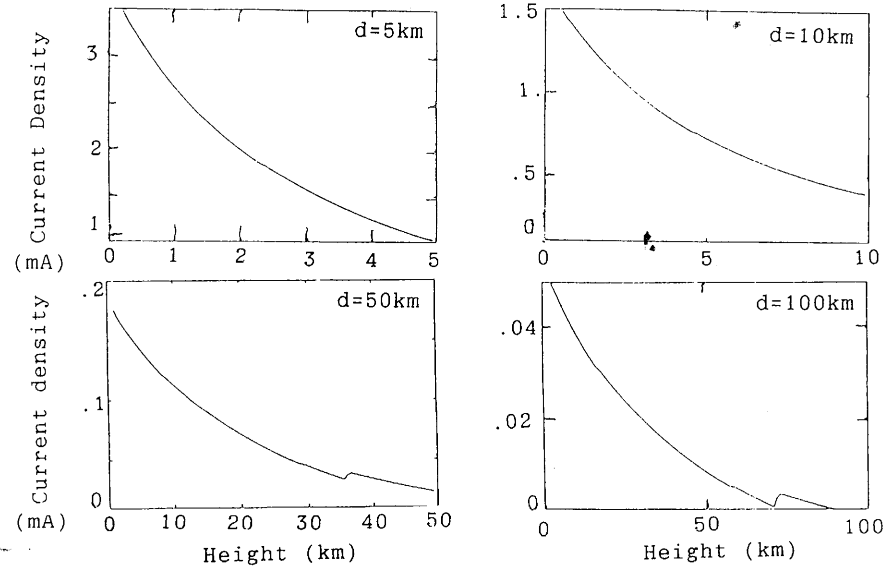

Fig. 4. Calculated magnetic flux intensity attenuation at the height of magnetic loop top vs. the conversion electric current density when assuming the exciting current is 1 A/m and the conductivity of soil is 10 S/m. (a) Depth of focus = 5 km, (b) depth of focus = 10 km, (c) depth of focus = 50 km, and (d) depth of focus = 100 km.

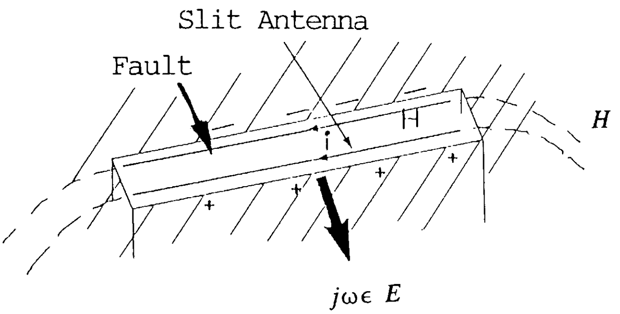

Fig. 5. Structure of a slit antenna on the ground surface and a fault excited by the electric potential induced by a magnetic flux loop originating at the focus of an earthquake.

earth's surface and the top height of magnetic flux loop from earth's surface changes between (h =) 0 to 50 km when the depth of focus is 5 km.

The order of the converted current densities at the surface is milliamperes, and this value seems to be high enough for the excitation of SEE. Figure 4(b) shows the same relationship curve for h from 0 to 10 km and a depth of focus of 10 km. Figure 4(c) shows the curve when h changes from 0 to 50 km and the depth of focus is 50

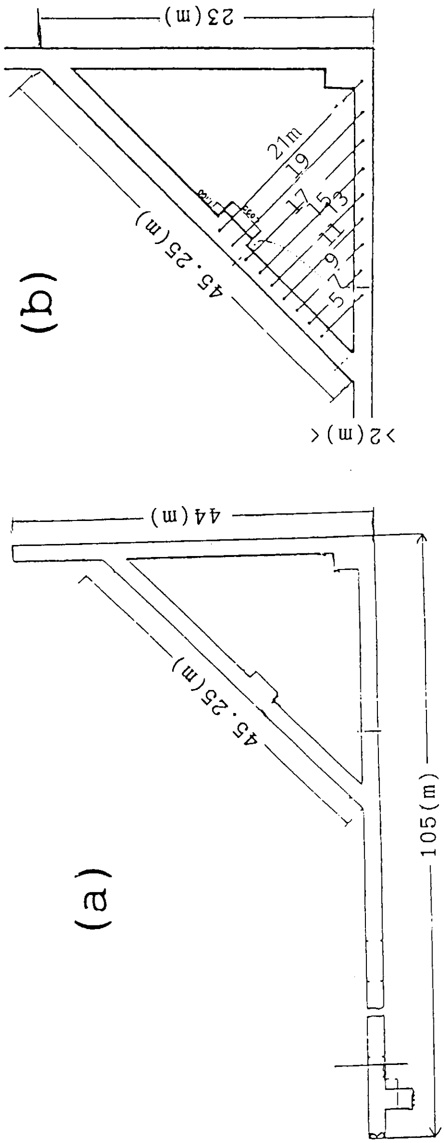

Fig. 6. (a) The geometry of the observation tunnel, and (b) the geometry of the tunnel at a portion of branch.

km and Fig. 4(d) shows the curve when h changes from 0 to 50 km and the depth of focus is 100 km. Even when the depth of focus is 100 km, the current density is high enough for SEE excitation.

As shown in Fig. 5, the best radiation efficiency would occur when the magnetic flux runs along the direction of the fault. The magnetic flux will induce a dipole electric field across the fault line, and this electric field will be able to excite a slit dipole antenna at ground level.

3. The Results of Penetration Loss of Magnetic Field Measurement in the Tunnel

We measured the attenuation of AC magnetic fields penetrating rock in the deep and long earthquake prediction tunnels of Nagano Pref., 200 km northwest of Tokyo. The purpose of these measurements was to obtain the backup data for our new theory.

Figures 6(a) and 6(b) show the layout and the size of the tunnel we used for our measurement. This tunnel is located in the western mountain side of Nagano city, Japan. Figure 6(b) shows the geometry of a portion of tunnel for our measurement, and it also illustrates the path between a straight and a branch section of tunnel. The cross section of the tunnel is 2 × 2 meters and the length of its straight portion was 105 meters.

Figure 7 shows the results of measuring magnetic field intensity outside the tunnel (free space). Each line (frequencies of 80, 160, 320, 560, 640, 880, 1040 and 1525 Hz) shows the beautiful attenuation characteristics of dipole field intensity vs. distance.

Figure 8 shows the characteristics between distance and magnetic field inten-

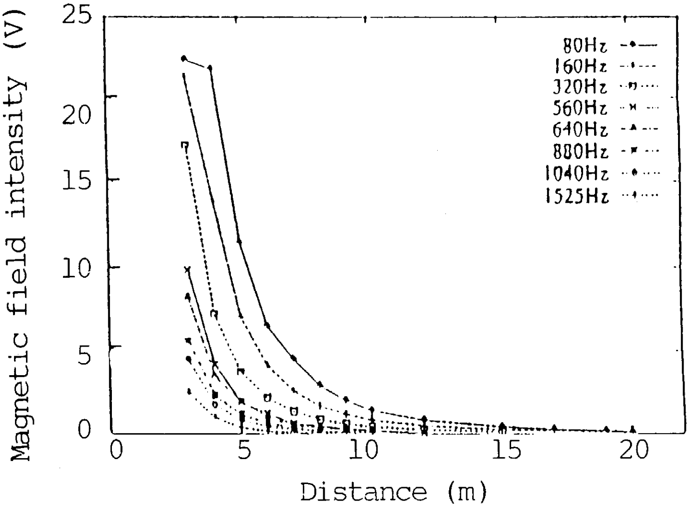

Fig. 7. The relation between magnetic field intensity and distance in free space.

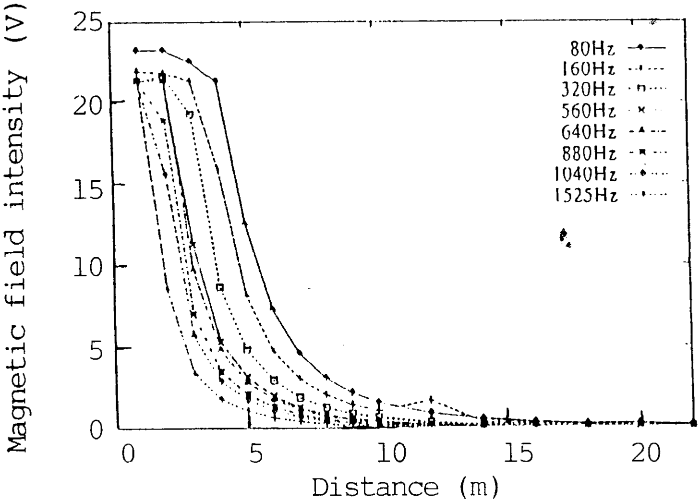

Fig. 8. The relation between magnetic field intensity and distance observed in a straight portion of tunnel.

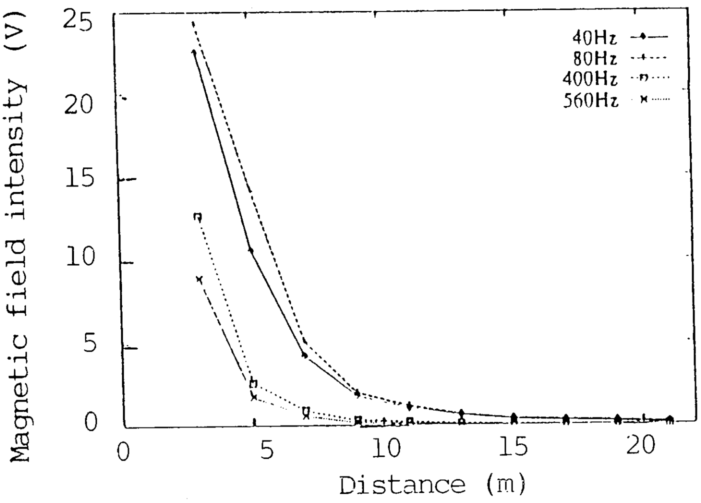

Fig. 9. The relation between magnetic field intensity and the thickness of the rock wall of tunnel.

sity observed in the straight tunnel. The results are the same as those observed in free space.

Figure 9 shows the observed characteristics between rock thickness (shown as "distance" in this figure) vs. magnetic field intensity. The measurements were made

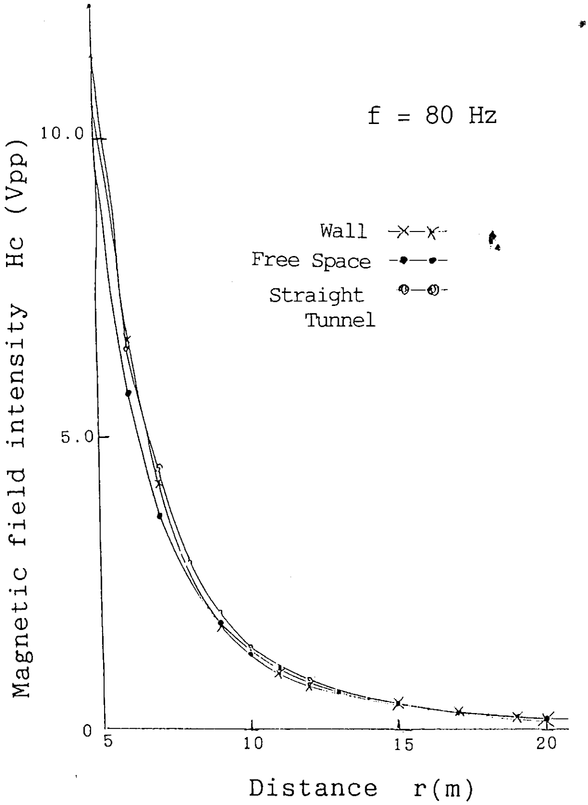

Fig. 10. The relation between the magnetic field intensities at 80 Hz and distance from transmitter loop and receiver sensor in free space, in the straight tunnel, and across a rock wall of tunnel.

in the two tunnels crossing each other at 45 degrees. A transmitting coil and receiving sensor were set inside of each tunnel respectively as shown in Fig. 6(b). In this case, the attenuation characteristics of these magnetic fields follow those of the dipole fields, and the results show that the penetration loss in such a thickness of rock is almost negligible.

Figure 10 shows, for comparison with Fig. 9, the observed results in free space, inside a straight tunnel, and at a crossover in the rock wall. The lines for these three cases mostly overlap, and the attenuation coefficient at 80 Hz is about 0.005 dB/m. For other frequencies at 40 Hz, 400 Hz, and 560 Hz, we obtained the results nearly similar to those at 80 Hz.

Observation results of the attenuation coefficient of electric field strength show a single dipole characteristic also kept as 10^{-3} relation for distance in the free space and inside of straight tunnel, but across the rock they show very high attenuation values that are roughly 20 dB or more lower than the values of magnetic fields. The experiment to obtain the exact values of attenuation characteristics for very weak electric fields has not yet been done. These results will, however, be obtained in near future.

4. Conclusion

We are developing a new theory to explain how SEE energy is transmitted from the focus area of an earthquake to the surface by the magnetic flux loop across the focus, and how it is converted to an electromagnetic wave and reradiated to increase the background noise level just before the earthquake. The results of our measurement in the tunnel are suggested to provide a support to our latest theory.

Although our new theory can explain the radiation mechanism of SEE, there remain some problems to be cleared up, such as the mechanism of determining the radiation frequencies, and the origin of magnetic energy of SEE generated by the rock crush, or other phenomena associated with earthquakes.

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